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Removal of Hazardous Metals from Waste Printed Circuit Boards by Chemical and Biological Methods.

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ABSTRACT

A printed circuit board, or PCB, is used to mechanically support and electrically connect various electronic components by using conductive tracks etched from copper sheets laminated on to a non-conductive substrate. The material composition of PCB is 40% of metals, 30% of ceramics and 30% of plastics. Since the PCB contains higher percentage of metals which are hazardous when discarded to the ecosystem the metals must be removed. The objective of the study is to remove hazardous metals from PCB by biological and chemical treatment methods. PCBs are collected from waste electrical and electronic equipment. The study is carried out for both economic and ecological reasons. The biological study involves the removal of hazardous metals by biological leaching process by using the fine powder obtained from the seed of "Persia Americana" commonly called as AVOCADO (butter fruit). The seed is powdered and processed which is used for removing the hazardous metals present in the waste PCB. In chemical method, the fine powder of discarded PCB is leached with mixed acids for the removal of hazardous metals from PCB. Thus both the methods were studied to achieve an eco-friendly technique.

Keywords*:* Printed Circuit Boards (PCB's), Metals, Mixed Acid Leaching, Biological leaching.

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INTRODUCTION

Electronic Waste (E-Waste)

"Electronic waste" (E-waste) may be defined as discarded electrical and electronic equipment. They may be discarded computers, office electronic equipment, entertainment devices, mobile phones, television sets and refrigerators. Rapid changes in technology, change in trend, changes in media (tapes, software, MP3) and falling prices have resulted in a fast-growing surplus of electronic waste around the globe. Display units (CRT, LCD, and LED monitors), Processors (CPU chips), memory (RAM), and audio components have different useful lives. Processors are most frequently out-dated (by software) and are more likely to become "e-waste", while display units are most often replaced while working without repair attempts, due to changes in technology.

An estimated 50 million tons of E-waste are produced each year. The USA discards 30 million computers each year and 100 million phones are disposed of in Europe each year [1]. The Environmental Protection Agency (EPA) estimates that only 15-20% of e-waste is recycled, the rest of these electronics go directly into landfills and incinerators. Asia itself disposes around 12 million metric tons of E-Waste. With increase in population, urbanization, capacity, economic growth and lifestyle orientation the developing countries will produce three times the amount of E-Waste producing right now in the next few years.

The amount of e-waste being produced - including mobile phones and computers - could rise by as much as 500 percent over the next decade in some countries, such as India. The United States is the world leader in producing electronic waste, tossing away about 3 million tons each year. China already produces about 2.3 million tons (2010 estimate) domestically, second only to the United States. And despite having banned e-waste imports, China remains a major e-waste dumping ground for developed countries.

Electrical waste contains hazardous but also valuable and scarce materials. Up to 60 elements can be found in complex electronics. In the United States, an estimated 70% of heavy metals in landfills come from discarded electronics. The two most commonly employed disposal techniques are Land filling and Incineration. Land filling technique is the most commonly employed technique throughout the India and it is the cheapest one. The waste are dumped in open pits and covered with soil. This may cause pollution to the nearby water bodies and agricultural fields because of the leaching behaviour of the heavy metals with the soil. Incineration is costlier than Land filling and does not cause much pollution. They use large furnace called Incinerators operating @ 9000C. If any untreated vapours are released to the atmosphere it can cause pollution [2-3].

Instead of disposing the equipment as waste, they can be dismantled and the various components in them can be recycled or reused in many ways. This not only reduces the cost involved in purchase or in the demand of raw materials but also reduces the hazardous caused because of disposing E-Waste.

Today the electronic waste recycling business is in all areas of the developed world as a large and rapidly consolidating business. Here equipment is reverted to a raw material form. This diversion is achieved through reuse and refurbishing. The environmental and social benefits of reuse include diminished demand for new products and raw materials, larger quantities of pure water and electricity for manufacturing and diminished use of landfills. Many outdated equipments are recycled in these days for the above merits. Audio-visual components, televisions, VCRs, stereo equipment, mobile phones, other handheld devices, and computer components contain valuable elements and substances suitable for reclamation, including lead, copper, and gold.

Printed Circuit Boards (PCB)

Printed Circuit Boards (PCB) is one of the most widely used components in making of electrical and electronic equipments. It is used in connecting electrical and electronic components using conductive pathways etched from copper. Today PCB's are virtually present in all electronic gadgets. So when equipments are discarded as E-waste, PCB's are also present in it. The PCB's contains almost 40% of metals. Some of the metals present in most PCB's are Copper (being the most around 30% by mass), Iron, Lead, Nickel, Aluminium, Tin, Gold, Silver, etc.

One of the major challenges is recycling the printed circuit boards from the electronic wastes. The circuit boards contain such precious metals as gold, silver, platinum, etc. and such base metals as copper, iron, aluminium, etc. Conventional method employed is mechanical shredding and separation but the recycling efficiency is low.

An alternative technology for removal of hazardous metals from waste PCB's is Hydrometallurgy. Magnetic separation is another one that is widely used for removal of ferromagnetic metals from non-ferrous metals and other non-magnetic waste. There are various electrical methods like Ion Exchange, Electro deposition, Electrostatic Separator also available but only the removal of Copper is given importance.

The material composition of 4 random PCB samples is given in Table 1

Table 1: Material Composition of various samples of PCB's

Materials	Sample A	Sample B	Sample C	Sample D
METALS Max 40%				
Copper (Cu)	20	26.8	17.85	23.47
Aluminium (Al)	2	4.7	4.78	1.33
Lead (Pb)	2	-	4.19	0.99
Zinc (Zn)	1	1.5		1.51
Nickel (Ni)	2	0.47	1.63	2.35
Iron (Fe)	8	5.3	2	1.22
Tin (Sn)	4	1	5.28	1.54
Au/ppm	1000	80	350	570
Pt/ppm	-	-	4.6	30
Ag/ppm	2000	3300	1300	3301

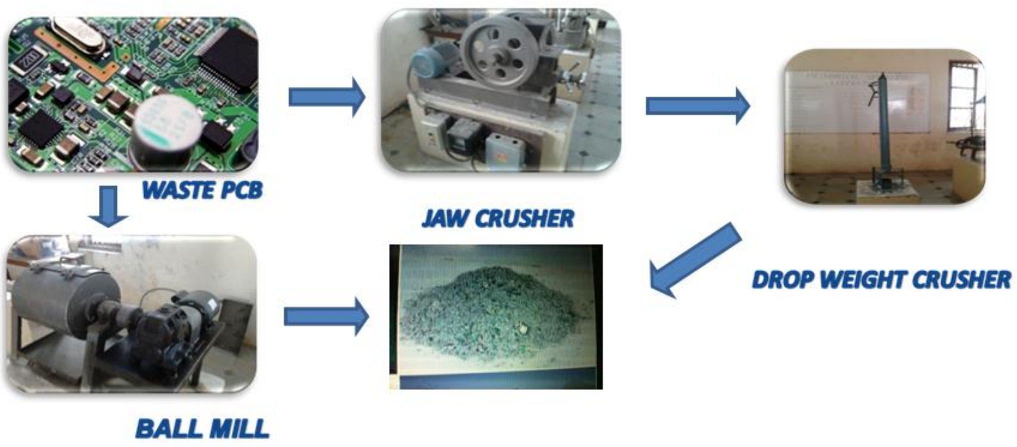
These when disposed by the conventional methods like land filling and incineration, the metals present in them may contaminate in the nearby lands or water bodies and pose risk to biotic and abiotic components. Thus the study suggests a suitable way for removing the hazardous metals by chemical and biological methods.

MATERIALS AND METHODS

PULVERIZING PCB'S

The PCB's are dismantled from the electrical and electronic devices. Then they are pulverized to fine powder. Crushing is done less than 2mm size. But crushing to 0.5mm size is preferable. This PCB is subjected to a series of crushers to obtain a fine powder. Particle of size 0.5mm preferred. The crushers used are Jaw Crusher, Ball Mill and Drop Weight Crusher. This crushing is carried for almost 30 minutes. The sequence of crushing is shown in figure 1.

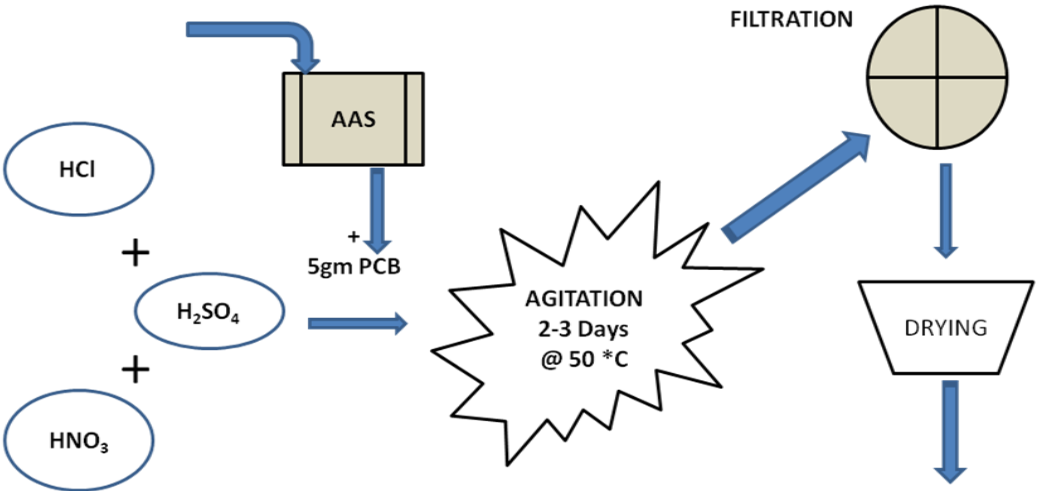
Figure 1: Equipment used for crushing PCB's



Chemical Treatment

The mixed acid is prepared by mixing equivalent volumes of sulphuric acid, Nitric acid and Hydrochloric Acid of equal normality. Here mixed acids of three different normalities (4N, 6N, 8N) are prepared i.e. mixing Sulphuric acid, Nitric acid and Hydrochloric Acid of 4N, 6N and 8N separately. In each case 10ml of each acid of same normality is mixed well to give the corresponding "Mixed Acid". Figure 2 gives the steps involved in the process of mixed acid leaching.

Figure 2: Steps involved in Process of mixed acid leaching



10ml of each acid of same normality are mixed in which 5grams of pulverized PCB's is added. The mixture is then subjected to agitation in a shaker with temperature and rpm controller. The agitation is carried out at 500C. The agitation is carried for 2 days and 3 days separately. The shaker is set to 200-300 rpm. After the period of agitation is over the contents are cooled in a water bath. The contents are then subjected to filtration where the resultant mass is separated off from the liquid. To clear the contents off completely from the vessel distilled water is used and they are filtered. The filtered mass is then dried in a Tray Dryer @ 1000C for 15-20 min. The drier is checked for every 5 minutes to prevent any burning. The sample of pulverized PCB's before treatment and the reacted PCB's that are filtered after treatment are subject to elemental analysis to find the percentage of hazardous metals present. Elemental analysis is done by AAS (Atomic Absorption Spectroscopy) technique [4-5].

Biological Treatment

Persea Americana seed used for creating the solvent for biological treatment is shown in figure 3

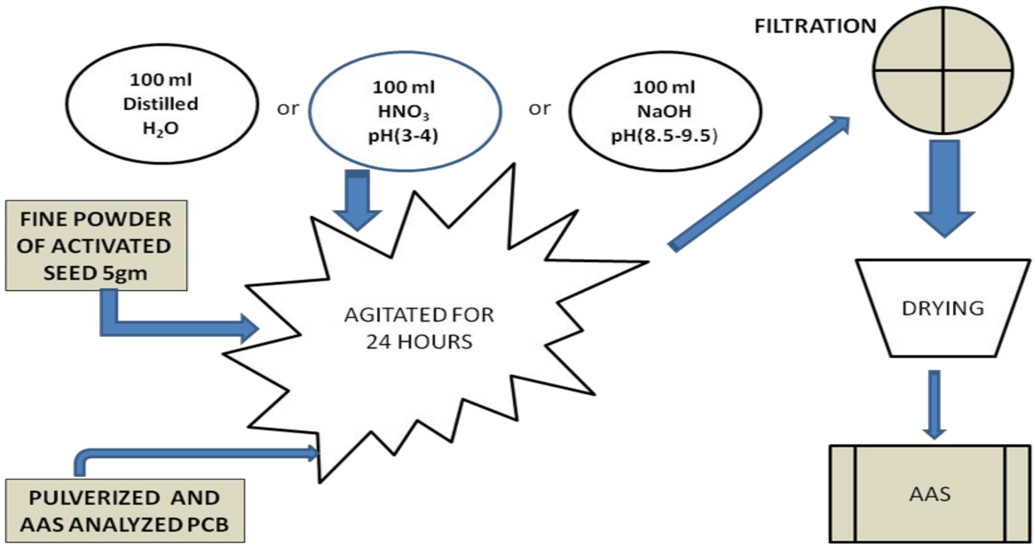
Figure 3: *Persea Americana* seeds used for creating the solvent for biological treatment

In biological treatment leaching process is carried out by using "Avocado" commonly called as Butter Fruit whose seeds are used as the raw material. The scientific name of Avocado is "Persea Americana". The solvent required for leaching is prepared as follows. The Avocado seeds in the form of activated carbon are going to be used as the in biological treatment [6]

The Avocado seeds are cut to pieces and sundried for 3-4 days to remove the moisture as much as possible. The dried seeds are removed off the debris and cleaned. Then it is again subjected to drying. The dried seeds are then subjected to crushing. The crushed powder is then subjected to screening where Mesh no 4 is used these are now taken in a Porcelain Crucible (withstands temperature of 12000C) and kept in a Muffle Furnace to convert into char. The Muffle Furnace is operated @ 5000C for 1 hour. After 1 hour we obtain char from the muffle furnace. It is cooled for nearly 1 hour and then taken in a Mortar where it is crushed using a pestle. The finely crushed activated char is taken in a beaker and then kept in an Autoclave @ 1300C for 3 hours, during the time duration constant pressure is maintained by regulating the release valve. Thereby we obtain activated carbon from Avocado seeds [7], [9-10].

Sequence of steps involved in the process of bio-solvent leaching is shown in figure 4

Figure 4: Steps involved in Process of process of bio-solvent leaching



The activated carbon from above is used as the raw material. The biological treatment is carried out in three different pH conditions acidic (pH 3-4), basic (pH 8.5-9.5) and neutral (pH 7).

Initially 10gm of activated carbon is mixed with Nitric Acid / Sodium Hydroxide/ Distilled water mediums whose pH are adjusted by adding either base or an acid to the distilled water to get required values. To this mixture 5gm of PCB is added. The resultant mixture above is agitated for 24 hrs. in a shaker at room temperature (30*C). The shaker is set to 200-300 rpm. After the period of agitation is over the contents are subjected to filtration where the resultant mass is separated off from the resultant liquid. To clear the contents off completely from the vessel distilled water is used and they are filtered [8]. The resultant mass is then dried in a Tray Dryer @ 100*C for 15-20 minutes. The resultant is subjected to elemental analysis to find the percentage of hazardous metals present in it by weight. The results obtained are compared and thereby the most effective procedure for biological treatment is concluded. And finally compare whether biological treatment or chemical treatment is the effective one.

RESULTS AND DISCUSSION

Chemical Treatment

The leaching process was carried out using 4N, 6N and 8N "Mixed Acids" for 48 hours. The results obtained are shown in Table 2, 3and 4

Table 2: Percentage of metals removed by leaching with 4N mixed acid

S. No	Hazardous Metals	Initial Composition (%)	Final Composition (%)	Removal Efficiency (%)
1	Copper(Cu)	4.65	0.18	96.13
2	Lead (Pb)	0.46	0.09	80.43
3	Iron (Fe)	0.36	0.016	95.55

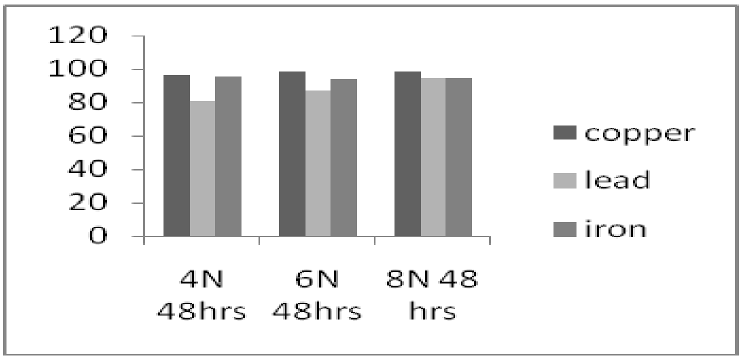
Table 3: Percentage of metals removed by leaching with 6N mixed acid

S. No	Hazardous Metals	Initial Composition (%)	Final Composition (%)	Removal Efficiency (%)
1	Copper(Cu)	4.65	0.062	98.67
2	Lead (Pb)	0.46	0.059	87.17
3	Iron (Fe)	0.36	0.023	93.61

Table 4: Percentage of metals removed by leaching with 8N mixed acid

S. No	Hazardous Metals	Initial Composition (%)	Final Composition (%)	Removal Efficiency (%)
1	Copper(Cu)	4.65	0.06	98.71
2	Lead (Pb)	0.46	0.024	94.78
3	Iron (Fe)	0.36	0.019	94.72

Figure 5: Percentage of metals removed by Chemical methods



From the above results it is clear that 8N Mixed Acid Leaching is more effective in removing Iron, Lead and Copper with a removal efficiency above 90% for all the metals.

Biological Treatment

The leaching process was carried out using a solvent prepared from a biological agent and reacted under acidic, neutral and basic pH conditions for 48 hours. The PCB sample was then dried and analysed in AAS. The results obtained are tabulated in Table 5, 6, 7.

Table 5: Percentage of metals removed by leaching with bio-solvent under acidic pH conditions

S. No	Hazardous Metals	Initial Composition (%)	Final Composition (%)	Removal Efficiency (%)
1	Copper(Cu)	5.28	2.14	59.47
2	Lead (Pb)	0.75	0.1	86.67
3	Iron (Fe)	0.36	0.046	87.22

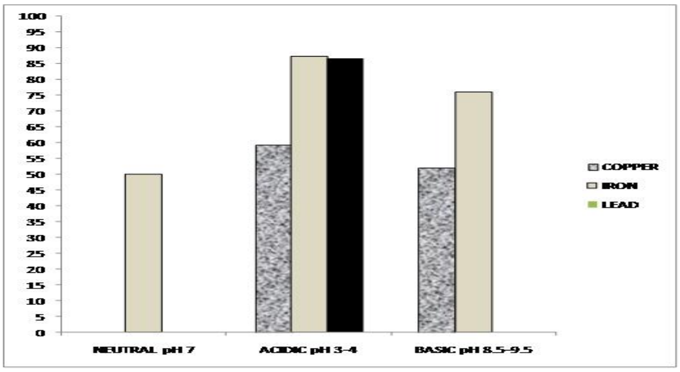
Table 6: Percentage of metals removed by leaching with bio-solvent under neutral pH conditions

S. No	Hazardous Metals	Initial Composition (%)	Final Composition (%)	Removal Efficiency (%)
1	Copper(Cu)	5.28	5.28	0
2	Lead (Pb)	0.75	0.75	0
3	Iron (Fe)	0.36	0.18	50

Table 7: Percentage of metals removed by leaching with bio-solvent under basic pH conditions

S. No	Hazardous Metals	Initial Composition (%)	Final Composition (%)	Removal Efficiency (%)
1	Copper(Cu)	5.28	2.14	52.08
2	Lead (Pb)	0.75	0.1	0
3	Iron (Fe)	0.36	0.046	76.11

Figure 6: Percentage of metals removed by Biological method



From the above results it is clear that Leaching in acidic pH is more effective in removing Iron, Lead and Copper with higher removal efficiency for all the metals.

CONCLUSION

When hazardous elements present in PCBs are disposed by the conventional methods like land filling and incineration, the metals present in them may pollute the land or water bodies and pose environmental risks to biotic and abiotic components

Chemical Treatment using 8N Mixed Acid Leaching was effective when compared to other Chemical Treatments (using 4N, 6N Acid Leaching) and more effective than Biological Treatments (using biological solvents under neutral pH, acidic pH and basic pH conditions).

The study suggests a suitable way for removing the hazardous metals by chemical and biological methods which is safe and economically viable.

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